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## Antiproton Stacking and Cooling

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February 24, 2004  
Lehman Review

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# Parameter Goals

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## ■ Goals

- Average Accumulation Rate  $40 \times 10^{10}$  pbars/hour
- Accumulate for 15 hours
- Final Pbar Parameters: **Stacked in Recycler**
  - Size  $\sim 600 \times 10^{10}$  pbars
  - Transverse emittance  $\sim 10\pi$ -mm-mrad (95% normalized)
  - Longitudinal emittance  $\sim 54$  eV-Sec

## ■ Inputs

- $280 \times 10^6$  antiprotons into Debuncher every 2 seconds
  - Transverse emittance =  $320\pi$ -mm-mrad (95% normalized)
  - Momentum Spread = 4%
    - Full acceptance of AP2 + Debuncher
  - Bunch lengths  $< 1.5$  nS

# Strategy

## ■ Present Operations

- Accumulator : final repository for antiprotons
- Stochastic Cooling:
  - Cooling Time ~ Number of particles
  - Limits
    - Stack size:  $\sim 300 \times 10^{10}$
    - Stacking rate: Falls off with stack size
- Transfers to Tevatron  
~1/day
  - "manual setup then transfer on event"

## ■ Future Operations

- Recycler : final repository for antiprotons
- Electron Cooling:
  - Cooling Time ~ Independent Number of particles
    - Stack Size:  $\sim 600 \times 10^{10}$
    - Stacking Rate: ~ Independent of Stack size
- Accumulator:
  - Optimized for flux, not density
  - Smaller Stack size:  $\sim 30 \times 10^{10}$
- Frequent (2/hour) transfers between Accumulator and Recycler
  - "setup & transfer on event"

## Accumulation process

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- Diffuse, low intensity pbar beam from target
  - Every 2 seconds
- Combination of stochastic and electron cooling
  - Combine many pulses
  - Cool transverse and longitudinal phase space
- Cold, high intensity pbar beam for the Tevatron

Density Variable: Number per phase space volume

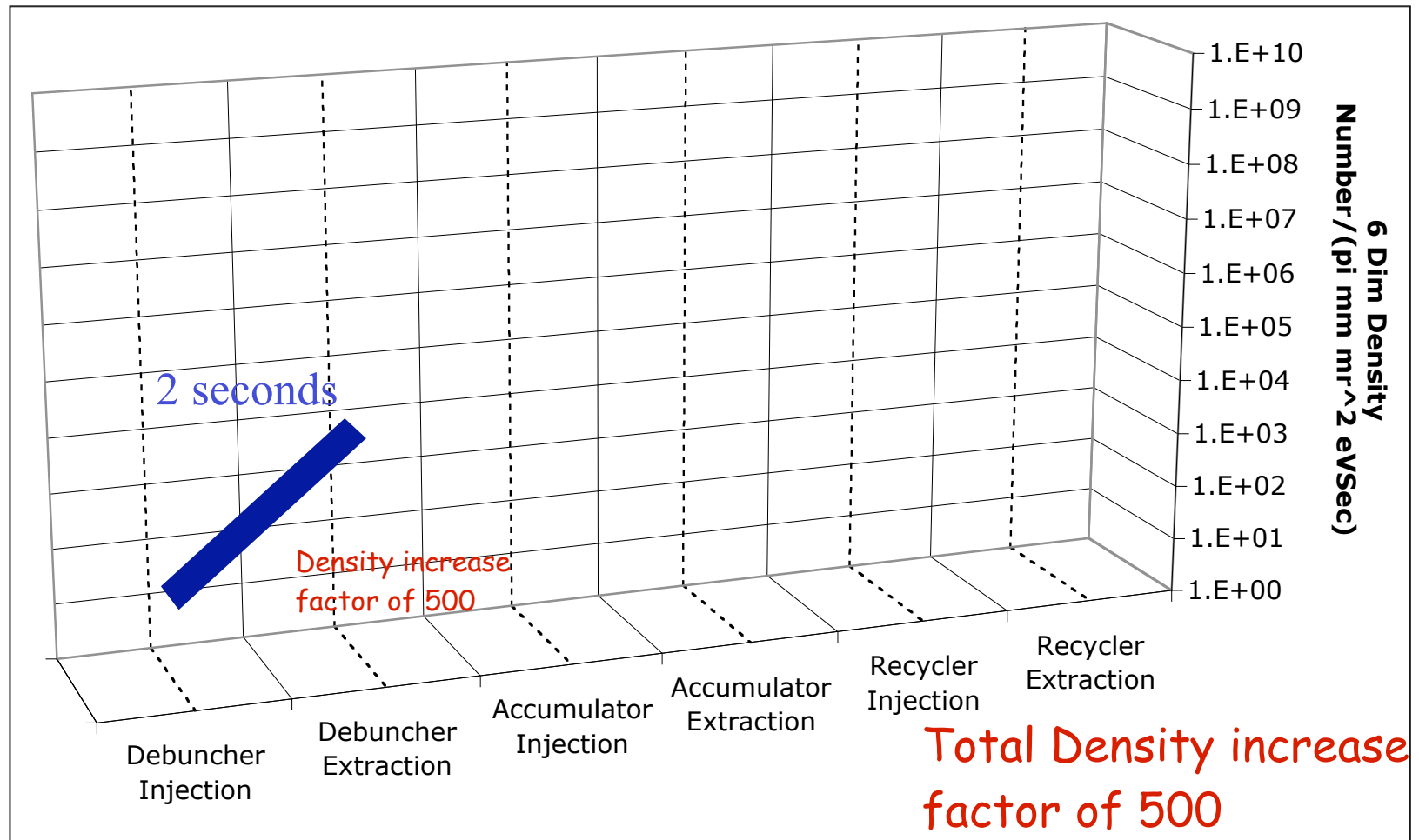
$$\frac{\rho_{6D}}{(\pi \text{ mm mr})^2 \text{ eVsec}} = \frac{N_{\text{particles}}}{\epsilon_H \epsilon_V \epsilon_L}$$

# Debuncher Cooling

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- Debuncher: Every 2 seconds collect beam from AP2, Cool, and Transfer to Accumulator
  - RF Bunch Rotation
    - Exchange momentum spread for time spread
    - $\rho_{6D} \sim 29$
  - Stochastic Cooling:
    - Liquid He temperature pickups
    - 4-8 GHz in 4 separate bands
    - Momentum: 10x compression in 2 Seconds
      - 95% width: 6 MeV/c
    - Transverse: 7x compression in 2 seconds
      - $45\pi$  mm mr
  - Extraction to Accumulator
    - $\rho_{6D} \sim 13,700$

# Phase Space Density -- Debuncher

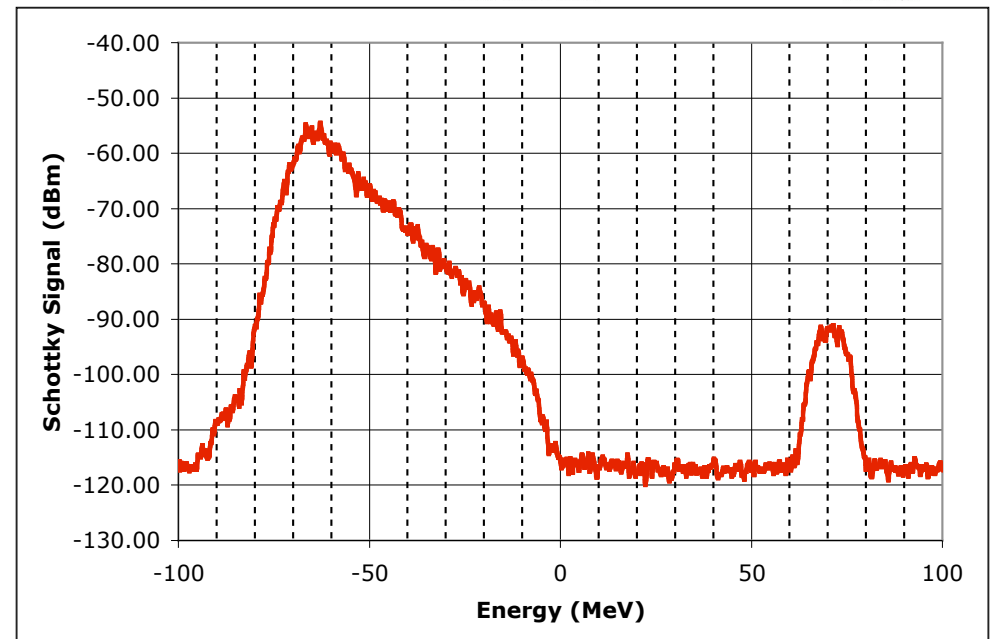
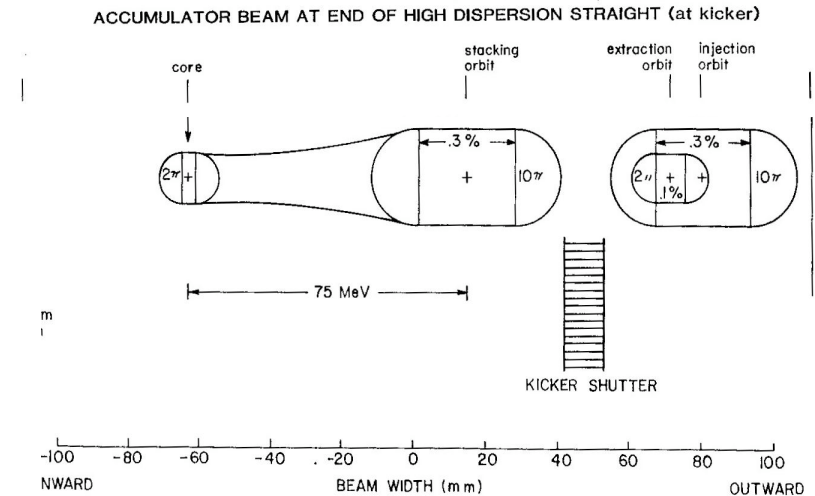


# Accumulator Cooling

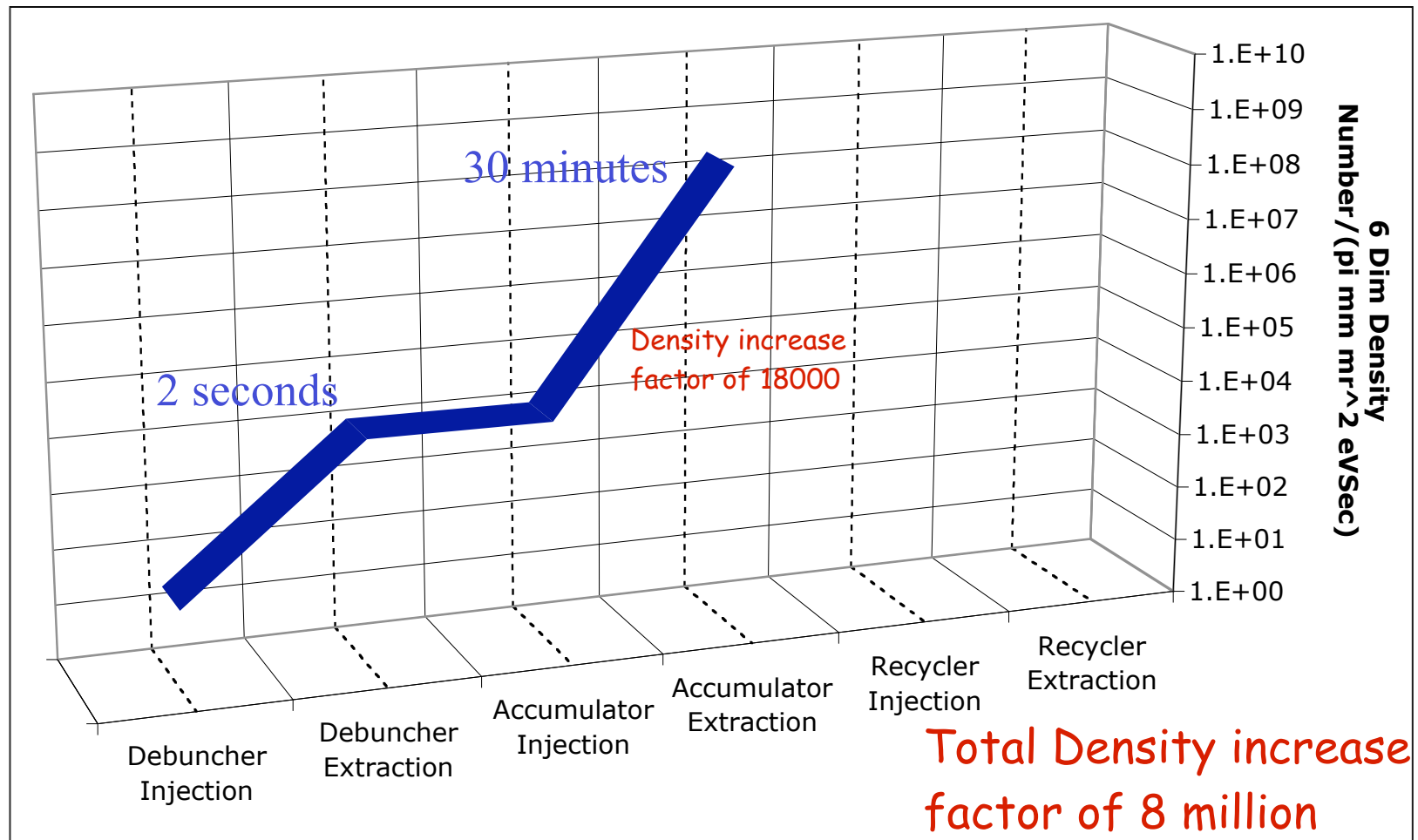
## ■ Accumulator Stacking

### ➤ Process

- Every 2 seconds:
    - Beam is injected
    - $\rho_{6D} \sim 13,000$
    - Beam is Bunched with RF
    - Moved with RF to the Stacking Orbit
    - Debunched on Stacking orbit
  - Stacktail pushes and compresses beam to the Core
  - Accumulator Transverse Core Cooling system cools the beam transversely in the Stacktail and Core
- Accumulate ~30 minutes, transfer to Recycler
- $\rho_{6D} \sim 237,000,000$



# Phase Space Density -- Accumulator





# Recycler Cooling

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## ■ Stochastic Cooling

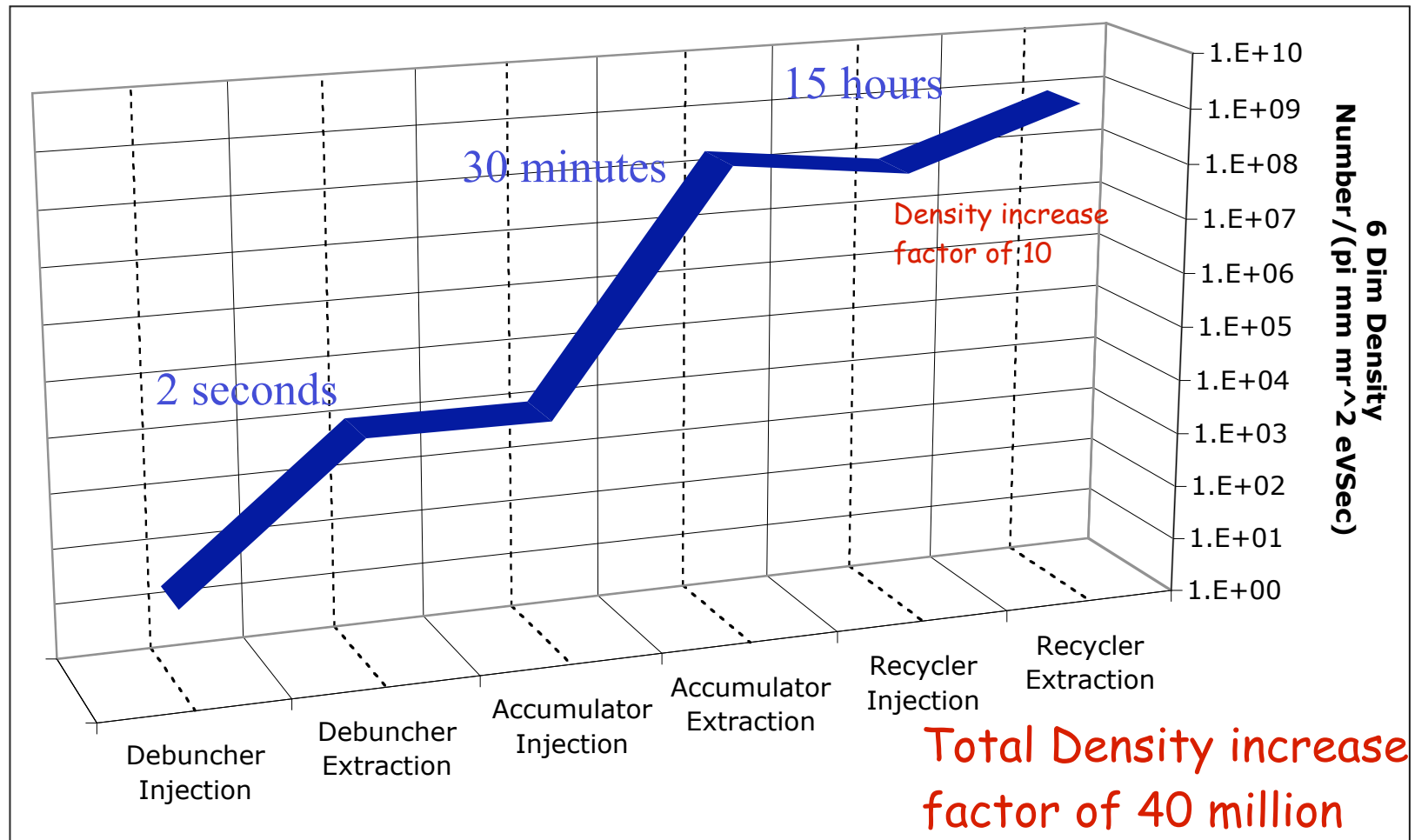
### ➤ Process: Every $1/2$ hour

- $\rho_{6D} \sim 100,000,000$
- $\sim 22 \times 10^{10}$  pbars in  $\sim 15$  eV-Sec and  $\sim 12 \pi$  mm mr
- Transverse stochastic pre-cooling of the injected batch
  - To cool within the reach of the electron cooling
  - kept separate from the main stack by barrier buckets

## ■ Electron Cooling

- Process: Every  $1/2$  hour
- Injected batch merged into the stack with RF barrier manipulations
- The Recycler stack
  - Is cooled mainly with electron cooling in all 3 planes
  - Weak transverse stochastic cooling for high amplitude particles
- After 15 hours:
  - $\rho_{6D} \sim 1,080,000,000$

# Phase Space Density -- Recycler



# Antiproton Stacking and Cooling Projects

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- Accumulator Stacktail Upgrade: 26.3.3
  - Project Leader: Paul Derwent
  - Major Objective: Upgrade the Stacktail system to handle  $90 \times 10^{10}$  pbars/hour
    - Increase bandwidth of the system to 2-6 GHz
- Recycler Stacking and Cooling: 26.3.4
  - Project Leader: Sergei Nagaitsev
  - Major Objective: Commission Recycler with stochastic cooling for use in operations
    - Commission Recycler stacking and transfer processes
- Electron Cooling: 26.3.5
  - Project Leaders: Sergei Nagaitsev & Jerry Leibfritz
  - Major Objective: Install an Electron Cooling section in the Recycler
    - Install a 4.3 MV Pelletron: 500 mA of electron current
    - Commission Electron Cooling for use in operations
- Frequent Antiproton transfers from Accumulator to Recycler: 26.3.6
  - Project Leader: Elvin Harms
  - Major Objective: Transfer Accumulator core to the Recycler
    - ~ 1 minute every 30 minutes
    - <50% emittance dilution
    - 95% transfer efficiency

# Technical Progress: Debuncher Cooling

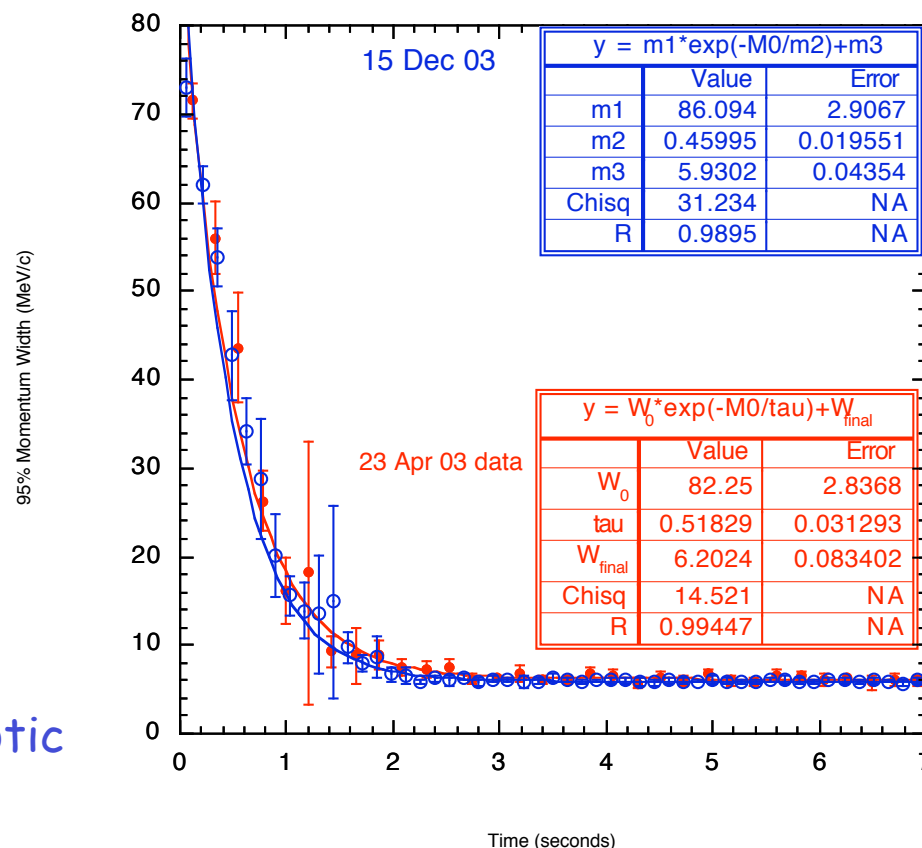
## ■ Debuncher Cooling:

### ➤ @ 2 seconds

- April 03: 7.9 MeV/c
- Dec 03: 7.0 MeV/c

- Goal: 6.0 MeV/c

- MI Beam Loading Compensation and Longitudinal dampers to lower initial width
- Change to optical notch filters to lower asymptotic width



## Technical Progress

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- Stacktail Cooling:
  - Pickup and kicker antenna design for 4-6 GHz band begun
  - Management decision: start procurement process for 24 TWTs and power supplies (12 month lead time from order) in Dec 03
    - Was driving need for Design Review in January 04
    - Design review: Conceptual and Implementation in March 04
- Frequent Transfers:
  - Power supply regulation of 120 GeV supplies in AP1 line:
    - Reverse Proton orbits stable at same level as with 8 GeV supplies
    - Regulation appears good enough to proceed
  - Installing ramp cards for testing

## Technical Progress: Electron Cooling and Installation

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- The R&D project at Wideband is on schedule
  - Milestone (500 mA) achieved on Dec 30, 2003
  - The beam current is reproducible but not very stable yet
  - Next and final milestone (beam properties) looks attainable
- The MI-31 building construction is on schedule and within budget
  - 82% complete at end of January
  - Tentative partial beneficial occupancy date 4/1/04
  - Tentative completion date 4/20/04
  - Currently on schedule and within budget
- Installation at MI-31 and in the tunnel
  - All Pelletron extension parts received
  - Miscellaneous components ordered
  - Electrical racks for building and control room are due and T&M requisition in-place to outfit them
  - Installation schedule developed

## Scope Changes

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- 26.3.3 Stacktail Cooling
  - Betatron system as originally proposed dropped
    - Design calculations gave 2% improvement -- not worth the effort
  
- 26.3.6 Frequent Transfers
  - Additional task: Energy match across Complex
    - Booster & Accumulator Extraction Energy  $\neq$  Recycler Energy
  - Changes in every machine (Booster, MI, Debuncher, Accumulator, transfer lines) to align complex to Recycler energy

## Summary

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- Through stochastic and electron cooling:
  - Diffuse low intensity beam -> cold high intensity beam
  - $\rho_{6D}$  increased by factor of 40 million
- Achieved by:
  - Optimizing Accumulator for flux
  - Integrating Recycler into operations
  - Utilizing Electron Cooling at 8 GeV
    - Size  $\sim 600 \times 10^{10}$  pbars
    - Transverse emittance  $\sim 10\pi$ -mm-mrad (95% normalized)
    - Longitudinal emittance  $\sim 54$  eV-Sec
- Significant Progress on Recycler and Electron Cooling projects



# Antiproton Stacking and Cooling Tasks

WBS		Base SWF (\$FY03)	Base M&S (\$FY03)	Start	Finish
26.3	Pbar Stacking and Cooling - Paul Derwent	\$3,864,620	\$3,871,998	3/3/03	12/6/05
26.3.1	Stacking and Cooling Integration	\$443,001	\$0	3/3/03	10/12/05
26.3.2	Debuncher Cooling	\$24,857	\$0	3/3/03	7/20/04
26.3.3	Stacktail Cooling	\$368,918	\$1,004,000	3/3/03	12/6/05
26.3.3.1	Momentum	\$368,918	\$1,004,000	3/3/03	12/6/05
26.3.3.2	Betatron Cooling	\$0	\$0	1/8/04	1/8/04
26.3.4	Recycler Stacking and Cooling	\$1,175,775	\$774,998	5/1/03	1/24/05
26.3.4.1	Develop Integration Performance Parameters	\$36,215	\$0	5/1/03	11/5/03
26.3.4.2	Commissioning Parameters Defined (Milestone)	\$0	\$0	10/31/03	10/31/03
26.3.4.3	Measure Parameters and Develop Commissioning Plan	\$1,111	\$0	11/18/03	1/16/04
26.3.4.4	Commissioning Plan Evaluation (Milestone)	\$0	\$0	2/9/04	2/9/04
26.3.4.5	RR Commissioned for Electron Cooling - now redundant	\$0	\$0	1/20/04	1/20/04
26.3.4.6	Further Recycler Commissioning - now redundant	\$0	\$0	1/20/04	1/20/04
26.3.4.7	Recycler commissioning	\$774,455	\$266,666	11/17/03	1/24/05
26.3.4.8	Recycler Upgrades	\$151,415	\$508,332	4/1/04	11/12/04
26.3.4.9	Management, evaluation and planning	\$212,578	\$0	12/1/03	12/30/04
26.3.5	Electron Cooling	\$1,100,620	\$1,556,000	3/3/03	6/1/05
26.3.5.1	Commission Full Beamline	\$543,717	\$88,000	3/3/03	3/31/04
26.3.5.2	Design and procure components	\$197,530	\$1,095,000	9/1/03	8/26/04
26.3.5.3	Disassemble Wideband Facility	\$32,550	\$37,000	3/1/04	7/22/04
26.3.5.4	Transport Components to MI-31	\$16,882	\$24,000	3/1/04	9/21/04
26.3.5.5	Install Pelletron at MI-31	\$56,986	\$141,000	3/1/04	10/5/04
26.3.5.6	Commission Pelletron	\$68,923	\$0	10/26/04	1/12/05
26.3.5.7	Install E-Cool Transferline	\$13,969	\$48,000	7/1/04	10/5/04
26.3.5.8	Modifications to MI/RR	\$9,083	\$106,000	5/1/03	9/7/04
26.3.5.9	Install Cooling Section in RR	\$29,891	\$17,000	6/1/04	11/19/04
26.3.5.10	Commission Cooling Section	\$29,685	\$0	10/20/04	1/27/05
26.3.5.11	Commission Electron Cooling	\$101,403	\$0	1/28/05	6/1/05
26.3.6	Rapid Transfers	\$751,450	\$537,000	4/1/03	6/14/05
26.3.6.1	Document Fast Transfer scheme	\$1,096	\$0	4/1/03	4/21/03
26.3.6.2	Beam Line Regulation	\$25,029	\$12,000	4/1/03	2/20/04
26.3.6.3	RT Software	\$243,944	\$0	4/22/03	4/12/05
26.3.6.4	Oscillation Feedback and Control	\$108,104	\$0	6/1/03	6/14/05
26.3.6.5	Diagnostics	\$357,200	\$505,000	7/1/03	3/16/05
26.3.6.5.1	P1, P2, AP1, AP3 53 MHz BPM upgrade	\$342,320	\$284,000	7/1/03	3/16/05
26.3.6.5.2	Hall Probes	\$14,880	\$221,000	6/15/04	9/7/04
26.3.6.6	Commission Fast Transfers	\$16,077	\$0	4/13/05	6/14/05
26.3.6.7	8-Gev Energy Match Across Complex	\$0	\$20,000	12/1/03	8/3/04

# Milestones

Milestones				
<b>26.3</b>	<b>Pbar Stacking and Cooling - Paul Derwent</b>			
<b>26.3.3</b>	<b>Stacktail Cooling</b>			
26.3.3.1.1.5	Review System Design: stacktail momentum (Milestone)	C	3/1/04	
26.3.3.1.2.4	Stacktail Reconfigured (option) (Milestone)	C	6/8/05	
26.3.3.1.7	Ready to install Stacktail Upgrade	C	8/8/05	
26.3.3.1.10	Stacktail Momentum Operational (Milestone)	A	12/6/05	
<b>26.3.4</b>	<b>Recycler Stacking and Cooling</b>			
26.3.4.2	Commissioning Parameters Defined (Milestone)	C	10/31/03	
26.3.4.4	Commissioning Plan Evaluation (Milestone)	C	2/9/04	
<b>26.3.4.7</b>	<b>Recycler commissioning</b>			
26.3.4.7.5.1	vacuum work in FY03 shutdown completed (Milestone)	C	11/17/03	
26.3.4.9.2	Vacuum performance	C	1/19/04	
26.3.4.9.4	Vacuum and Machine admittance	C	1/27/04	
26.3.4.9.6	MI to RR Trans >85% round trip <3 pi growth	C	2/27/04	
26.3.4.9.8	Stacking Performance with 100E10	C	3/15/04	
26.3.4.9.10	Equilibrium Properties at 200 E10	C	4/5/04	
26.3.4.9.12	Recycler Rapid Transfer Commissioned	C	4/20/04	
26.3.4.9.14	Extraction Commissioned	C	6/8/04	
26.3.4.9.16	Recycler commissioned for Electron cooling	A	6/1/04	
<b>26.3.5</b>	<b>Electron Cooling</b>			
26.3.5.1.11	Demonstrate beam properties at Wide Band Lab (Milestone)	C	3/31/04	
26.3.5.2.1	Pelletron extension parts received	C	3/1/04	
26.3.5.6.1	Pelletron Installed at MI-31 (Milestone)	C	10/26/04	
26.3.5.12	Electron Cooling Operational (Milestone)	A	6/1/05	
<b>26.3.6</b>	<b>Rapid Transfers</b>			
26.3.6.5.1.2	Review specifications and plan for transfer line BPM upgrade	C	5/12/04	
26.3.6.7.3	Review 8Gev energy match plan	C	4/29/04	
26.3.6.8	Rapid Transfers Operational (Milestone)	A	6/14/05	